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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

High Humidity Extremes in the Upper Air

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United States Air Force

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AERONOMY LABORATORY PROJECT 8624

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES

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High Humidity Extremes in the Upper Air

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Abstract

The 1- and 5-percent world-wide high dew-point envelopes from the surface to 10 km are derived statistically from operational rawinsonde data. Values at each level are based on the most extreme month at the most extreme location, as required for the revision of MIL-STD-210A, "Climatic Extremes for Military Equipment." A 1-percent frost-point envelope model is extended to 80 km. It is based on limited experimental data and theory. Dew- (frost)-point envelopes and corresponding mixing ratios are tabulated to 80 km.

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1. INTRODUCTION

Most military equipment designers are aware of the problems produced by high humidities. Near the surface, these problems include corrosion, fungus and bacterial growth, electronic circuitry breakdowns, air conditioning, etc. At altitude, there are problems such as attenuation of infrared components used in satellites and missile tracking devices, cabin environment control, and index of refraction effects on radar tracking.

Minute quantities of water vapor also become extremely important to certain functions. For instance, a missile tracking device which is dependent on the reception of a minimum detectable signal by an infrared receiver must be designed for some threshold level which takes into consideration the highest humidity normally expected. One currently popular theory of a non-varying "dry stratosphere" (a mixing ratio of 2×10^{-6} grams of water vapor per gram of dry air)(Gutnick, 1961) could be used to establish the required threshold signal level. If a designer accepts this theory, and the atmosphere under which the tracker operates has a mixing ratio of 15×10^{-6} g/g (a value observed by other scientists) (Sissenwine et al, 1968a), the signal could penetrate the atmosphere less than one-half the distance expected by the designer, depending on altitude and operating wavelength of the receiver.

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There are two categories of equipment problems related to high humidities: those associated with high moisture content which can be described in terms of absolute humidity, dew point, or vapor pressure (all of which have a one-to-one correspondence); and those problems associated with high relative humidity, which is a ratio of the amount of water vapor in a parcel of air to the maximum (saturation) amount the parcel is capable of holding at that temperature.

The first category, high moisture content, is of primary concern in the operation of equipment. The second category, high relative humidity, is usually related to corrosion and fungus (Sissenwine, 1953) during long-term exposure at fairly high temperatures, a "withstanding" problem, mentioned in the next paragraph. The operational problem, probability of occurrence of high dew points, is the major concern for high altitudes and the subject of this report. However, an important operational exception, where relative humidity extremes aloft must be considered, is that of high voltage breakdown and leakage along insulators which results in malfunctions of electronic components. Extremes and durations of high humidity at surface levels is the subject of a report recently published by the U. S. Army Natick Laboratories (Dodd, 1969).

Both of the reports just described were initiated in support of a revision of MIL-STD-210A, "Climatic Extremes for Military Equipment," which is a DoD directed effort. Guidance by the Joint Chiefs of Staff indicates that the atmospheric extremes for which equipment should operate are generally those with a 1-percent risk of failure during the worst month over the geographical area of the world at which each meteorological element has its greatest extreme. For the upper air, extremes at different altitudes need not occur neither over the same geographical areas nor simultaneously at all levels. Another set of extremes that equipment must "withstand " but not necessarily operate under, is also being provided. In general, such "withstanding" extremes are applicable to long period (many years) exposures and storage and, therefore, are being provided only for surface levels. Since there may be times when it is advisable to design for a higher risk than 1-percent values for worst season, worst area, and 5-percent risk will also be provided in the new MIL-STD-210B.

2. DATA

Gringorten et al (1966) incorporates data from about 1500 surface stations and 400 upper air stations, and Dodd (1969) gives data from 215 stations between latitudes 40° N and 40° S. Comparisons between Northern and Southern Hemispheric data reveal that higher dew-point extremes are observed in the Northern Hemisphere.

Areas of high absolute humidity extremes in the lower levels must have large, hot bodies of water at the surface. As shown in Figure 1, the area of primary interest, determined from Gringorten et al (1966), is over waters surrounding the Saudi Arabian Peninsula, particularly the Persian Gulf, the Gulf of Aden, and the Red Sea, where surface water temperatures reach about 35°C (95°F), and dew points of 30°C (86°F) are exceeded 5 percent of the time. Other areas of possible extreme humidities are found in the Bay of Bengal and the Gulf of Mexico.

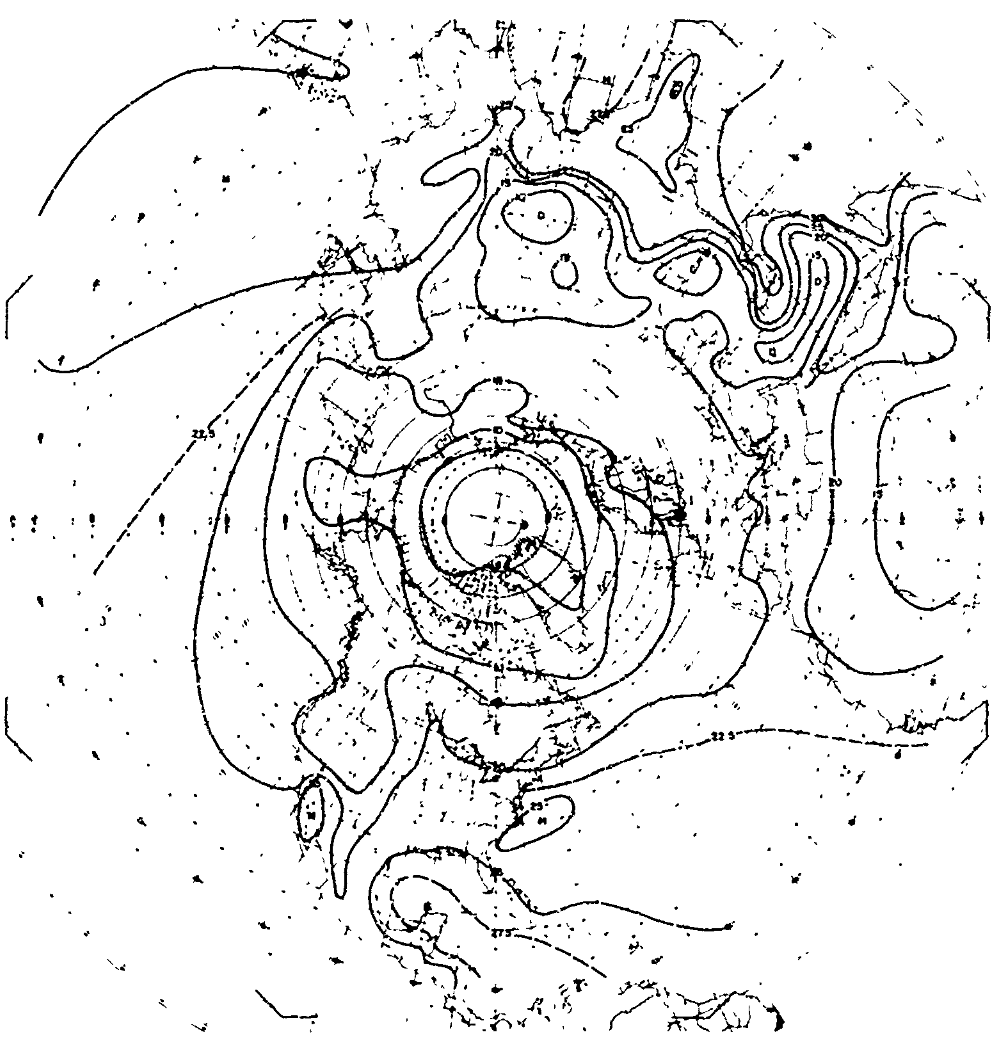

Figure 1. Northern Hemisphere Surface Dew-point Temperature (Isopleths in °C) Exceeded 5 percent of the Time During July. (After Gringorten et al, 1966)

Gringorten et al (1966) contains information for standard radiosonde heights up to 400 mb. It shows that the center of maximum dew point observed at the surface over Arabia and Bay of Bengal waters shifts eastward and northward with increasing altitude. At the 400-mb surface, it is located in south central Asia as shown in Figure 2.

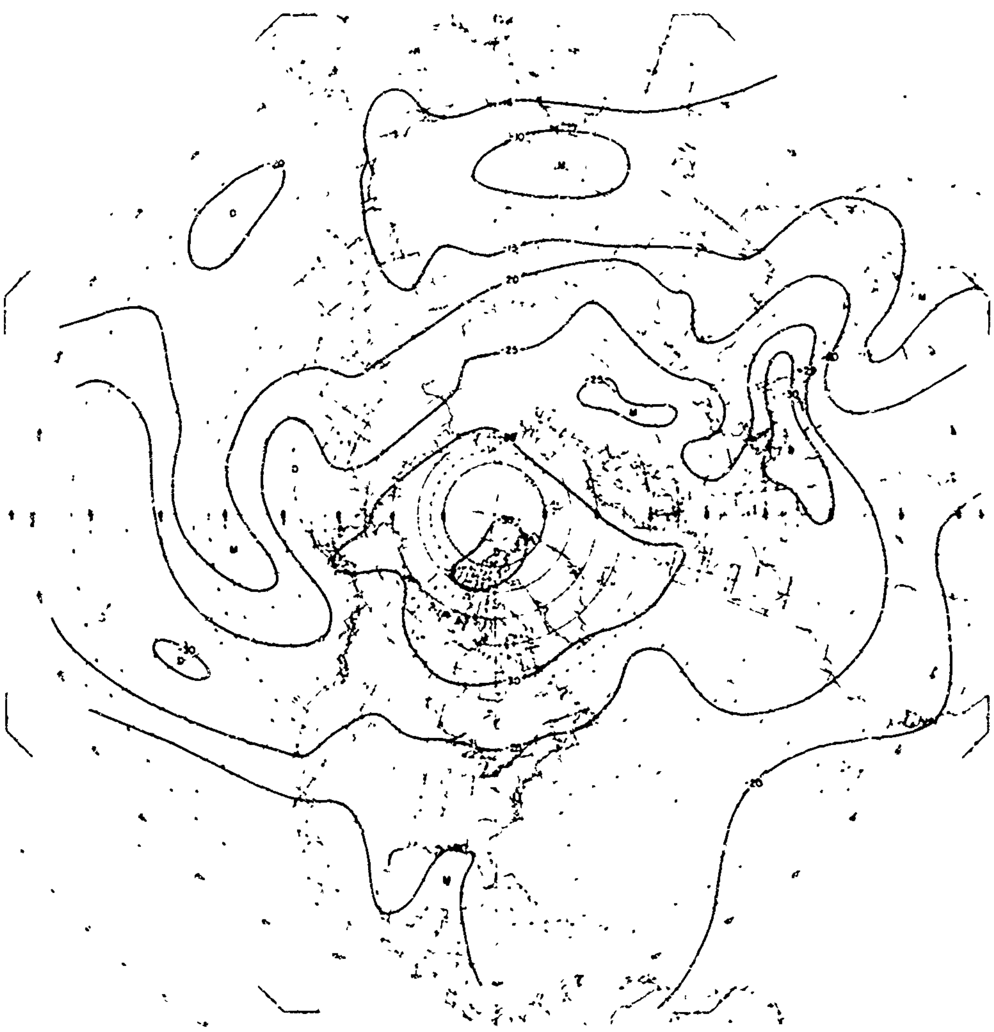

Figure 2. Northern Hemisphere 400-millibar Dew-point Temperature (Isopleths in °C) Exceeded 5 percent of the Time During July. (After Gringorten et al, 1966)

Stations with the greatest potential for high humidity extremes at the various levels were chosen from these charts. Monthly probability distributions were then plotted to determine the upper extreme dew points from frequency distributions completed at the National Weather Records Center and made available through the Air Weather Service's Environmental Technical Applications Center. The probability distributions were determined by ordering the observations from the smallest to the largest and using the plotting rule:

$$P(i) = \frac{i - 3/8}{N + 1/4} ,$$

where (i) is the order and N is the total number of values (Blom, 1958). The upper 1- and 5-percent dew- (frost)-points for radiosonde heights resulting from this procedure are presented in Table 1, and the 1-percent extremes are plotted in Figure 3. Locations, altitude, and period of record for the high-humidity stations are presented in Table 2.

Table 1. World-wide 1- and 5-percent High Dew-point Temperature for Selected Radiosonde Levels Up to 400 mb

Height	Dew Point Temperature (°C)		Location	Month
	1%	5%		
Surface	33.6*	31.9*	Sharjah, Arabia	VII
	31.9	30.9	Sharjah, Arabia	VIII
	31.9	27.8	Khanpur, Pakistan	VIII
	30.8	29.2	Bahrein, Arabia	VIII
	30.6	29.0	Muscat, Arabia	VI
	26.5	25.4	Pensacola, Florida	VII & VIII
850 mb	27.4*	25.4*	Peshawar, Pakistan	VII
	22.7	19.0	New Delhi, India	VI
	17.1	16.0	Del Rio, Texas	VIII
700 mb	20.0*	14.9	Peshawar, Pakistan	VIII
	19.5	15.6*	Peshawar, Pakistan	VII
	15.0	12.0	New Delhi, India	VII
	14.9	11.2	Calcutta, India	VIII
500 mb	2.2*	-1.4*	Calcutta, India	VIII
	0.5	-1.9	New Delhi, India	VII & VIII
	0.0	-2.0	Adag Mamar, China	VI
	-0.1	-1.9	Lhasa, China	VIII
400 mb	-9.7*	-11.0*	Lhasa, China	VII & VIII
	-10.0	-11.1	Adag Mamar, China	VII
300 mb	-23*	-25*	Lhasa, China	VII & VIII

*Values used in determining envelopes of upper extreme dew-point temperature

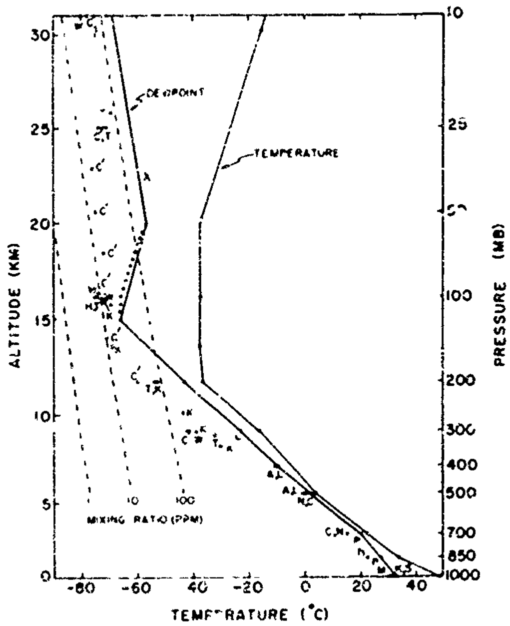

Figure 3. Upper 1-percent Temperature and dew- (frost)-point Envelopes, Surface to 30 km. (See Table 2 for explanation of letter designations)

The 1-percent temperature envelope for radiosonde heights for MIL-STD-210B has not yet been finally specified. The curve on the right in Figure 3 is a preliminary envelope of upper 1-percent temperatures and is shown merely for reference, since dew-points (or frost points) cannot exceed temperature. It does not correspond to the dew-point envelope in either space or time. The 1-percent maximum dew-point for the surface was determined to be 33.6°C (92.5°F) at Sharjah, Saudi Arabia. As shown in Table 1, other extremely humid surface locations at Muscat and Bahrein, Arabia, and at Khanpur, Pakistan support this value. These are denoted by their first initials in Figure 3.

Aloft, at the 850- and 700-mb levels, the humidity center moves northeastward to Peshawar, Pakistan where the 1-percent high dew points are 27.4 and 20.4°C, respectively. The 1-percent dew points at New Delhi and Calcutta, India are about 5°C lower at these levels. At 500 mb, the humidity center has shifted further east with its maximum over Calcutta and extends northeastward into the Tibetan Plateau region of southwestern China. This latter region then becomes the center of maximum humidity at the altitudes of 400 and 300 mb where the 1-percent extremes for the months of July and August are -10 and -23°C, respectively, over Lhasa, China.

The 400-mb pressure altitude is usually the upper limit for the radiosonde capability of measuring humidity. Reliable measurements at the unusually high altitude of 300 mb are only possible for upper extremes of humidity because of warm temperatures with which they are associated. Above the heights of radiosonde-observed humidities, measurements are limited to research data with specially designed instrumentation. These research data have been collected over only a few geographical areas, and the samples are too small in number to provide reliable frequency distributions. Some of them are of questionable accuracy. These data limitations make it virtually impossible to arrive at true 1-percent probable extremes for altitudes at and above 10 km. Even rough estimates are difficult to make.

Table 2. Geographical and Observational Information for Selected Stations which Observe High Humidity

Designation on Figure 1	Location	Station Number	Period of Record	Approx. no. of Observations	Latitude	Longitude	Elevation (ft. msl)	Remarks
S	Sharjah, Arabia	40419	1949-1953	88	25°21N	55°23'E	6	Daily 12 GMT Observations
K	Khanpur, Pakistan	41718	1954-1963	629	28°39'N	70°41'E	297	Approx. twice daily Observations (0300 and 1200 GMT)
B	Bahrein, Arabia	40427	1949-1953	97	26°16'N	50°37'E	6	Daily 12 GMT Observations
M	Muscat, Arabia	40460	1949-1953	107	23°35'N	58°35'E	20	Daily 12 GMT Observations
	Pensacola, Florida	WBAN 03855	1945-1967	16,562	30°21'N	87°16'W	118	Hourly Observations
P	Peshawar, Pakistan	41530	1957-1964	113	34°01'N	71°35'E	1177	
N	New Delhi, India	42182	1946-1953 1957-1962	216 to 413	28°35'N	77°12'E	710	Safdarjung
	Del Rio, Texas	WBAN 22001	1954-1962	781	29°20'N	100°53'W	1102	
C	Calcutta, India	42809	1954-1962	300 to 400	22°39'N	88°27'E	33	Dum Dum
A	Adag Mamar, China	55299	1957-1962	152	32°00'N	92°07'E	4000	Heiho
L	Lhasa, China	55591	1957-1962	275	29°43'N	91°02'E	3658	Lasa
Experimental High-Altitude Humidity Observations								
T	Trinidad, W. Indies		1964-1965	2[illegible]				Naval Research Labs. (Mastenbrook, 1966)
W	Washington, D.C.		1964-1965	2[illegible]				Naval Research Labs. (Mastenbrook, 1966)
H	Hyderabad, India		1961	3				Naval Research Labs. (Mastenbrook, 1962)
K	Kwajalein, Atoll, Marshall Islands		1963	5				Naval Research Labs. (Mastenbrook, 1965)
C'	Chico, California		1965-1966	17				Air Force Cambridge Research Laboratories (Sissenwine et al., 1968b)

The Naval Research Laboratories have conducted numerous high-level humidity measurements at Washington, D. C., Trinidad, and Kwajalein. The highest frost points measured at these locations are indicated in Figure 3 by the station initial at various altitudes, about 300 mb and above. The Air Force Cambridge Research Laboratories' Design Climatology Branch also conducted an intensive stratospheric humidity measurement program (Sissenwine et al, 1968b). The humidity element was a highly sophisticated, alpha-radiation frost-point hygrometer which was carried to altitudes up to 32 km by 0.5 million cubic-foot balloons that were launched from Chico, California. A "Mid-Latitude Humidity Profile" resulted from this program. This profile represented typical mid-latitude conditions over a year (not a true mean). It may be very far from a 1-percent extreme humidity profile, regardless of location, but at least it provided a shape and a starting point. The highest frost points observed in this program are denoted by the initial C' in Figure 3. However, none of these research observations could really be considered as 1-percent extreme frost points.

The tropopause is known to be a moisture trap for water vapor originating at surface levels, since it is the coldest level above the surface, and the frost point cannot exceed the temperature. Therefore, it was decided that the highest humidity at the 200-mb level, which is in the troposphere at low- and mid-latitudes, would be observed in an area where near-saturation occurs in warm (polar) tropospheric air just below the tropopause. This area seems to be in southern Russia, a location reasonably consistent with the movements of the humidity centers from lower altitudes (Goldie et al, 1958). The upper 1-percent extreme frost point at 200 mb for July at 55°N 90°E was then determined to be -43°C by assuming a 50-percent relative humidity for the 1-percent warm tropopause temperature. This 50-percent relative humidity is consistent with other results of humidity studies conducted for altitudes at and slightly below the polar tropopause level (Sissenwine et al, 1968a; Raschke, 1966). By using the 5-percent warm tropopause temperature in an analogous procedure, the upper 5-percent frost point at 200 mb was determined to be -49°C.

The moisture source for high humidities in the 15 to 20 km level develops from a completely different physical phenomenon, cumulonimbus clouds, which reach these altitudes 1 percent of the time in certain areas. Figure 4 is taken from a recent study on the penetration of cumulonimbus clouds to very high altitudes (Kantor and Grantham, 1968). The analysis in this figure is based on the occurrence of at least one radar echo within a 100-mile radius. It shows that cumulonimbus clouds occur within the 18- to 20-km altitude increment 1 percent of the time around New Orleans, Louisiana and Kansas City, Missouri in July. Assuming saturation in and adjacent to these clouds, the temperature profile can be considered as a dew-point profile. A July mean of the temperature soundings taken

Figure 4. Probability of the Occurrence of at Least One Radar Precipitation Echo Between 60- and 65-kft Altitude Within a 100-mile Radius During July. (After Kantor and Grantham, 1968)

very near the periods of radar-observed echoes at these levels is shown as a series of dots in Figure 5. It may be considered as the 1-percent frost point. Only that portion between 15 and 20 km of the mean sounding affected the shape of this 1-percent extreme envelope, since at lower levels, the mean sounding was colder than the 1-percent envelope which was obtained from background outlined above, and cumulonimbus development was considered to go no higher than 20 km with 1-percent probability. Echoes do go higher than 20 km but only at less than 1 percent of the time even in the worst months. Therefore, through the 20-km level, a fairly reliable basis is established for the upper 1-percent dew- (frost)-point envelope. Above this level, there are only research observations, as discussed earlier and shown in Figure 3, none of which were made over areas where high frost-point temperatures are expected. Also, observations were not obtained frequently enough to approximate the distribution even in the areas over which experiments were performed. They are not nearly as extreme as is indicated by the dotted curve at 15 to 20 km. However, there is one additional scientific fact on which extrapolation can be based – the determination that noctilucent clouds, which occur near altitudes of 80 km, are composed of ice-covered particles. Based on temperature measurements made in the presence and then in the absence of noctilucent clouds, plus the most accepted hypothesis on the formation and composition of these clouds (Theon et al, 1967), it was determined that a conservative value for the mixing ratio at 80 km is 5 ppm, that is, 5 grams of water vapor in a volume of 1,000,000 grams of dry air. The 80-km frost point for this assumption is about -122°C.

Based upon the assumption that there are no major water sources or sinks between the height to which tropospheric clouds penetrate the tropopause and the mesopause, the 1-percent high frost-point envelope was then linearly extended from the 20-km value of -56°C, which is nearly 200 ppm, to -122°C at 80 km, producing the slope shown in Figure 3 for altitudes above 20 km. Consequently, above 10 km (that is, above the height of radiosonde humidity) and especially for altitudes above 20 km, this extension is not a statistically derived envelope and can be considered only an estimate of the 1-percent frost-point temperature envelope. At the time of preparation of this report, no evidence supporting this envelope appeared in the

literature. Such evidence was uncovered shortly afterward. The x, shown at about 22 km in Figure 3, represents radiosonde temperature recorded during a display of unusually high clouds near the White Sands in June 1969 and identified by Sharp (1970) as of the nacreous type, usually associated with strong westerly flow. (These may have been the blow off of cirrus from a cumulonimbus penetrating the tropopause over eastern Texas, since east winds are found at this altitude and season.) Altitude was determined accurately by triangulation. Assuming saturation conditions at this altitude, this temperature is also the frost point. Although this point is somewhat outside the 1-percent high frost-point envelope, the likelihood of observing nacreous clouds over White Sands is lower than 1 percent. Therefore, this evidence supports the 1-percent high dew- (frost)-point envelope at the 22-km level.

3. RESULTS

Figure 5 compares the envelope of upper 1-percent extreme humidity, developed herein, to the 1-percent high-temperature curve (preliminary below 30 km) from the surface to 80 km. The 1962 U. S. Standard temperature profile is also shown. It again should be emphasized that the dew point and temperature curves are envelopes, not profiles, and that the two envelopes do not necessarily correspond to one another in either time or space.

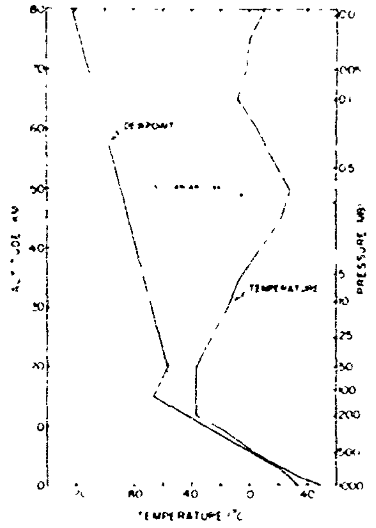

Figure 5. Upper 1-percent Envelopes of Air and Dew- (frost)-point Temperature Up to 80 km. U. S. Standard Atmosphere, 1962 shown for comparison

Figure 6 shows the mixing ratio envelope resulting from the upper 1-percent dew- (frost)-point temperature envelope presented in Figure 5, assuming the U. S. Standard Atmosphere, 1962. The computation of mixing ratio from dew- (frost)-point requires the use of the saturation vapor pressure. It was decided that for levels through 10-km saturation vapor pressure over water would be used. Above this level saturation vapor pressure over ice was used, thus accounting for the break in envelope at 10 km. Included for comparison in Figure 6 is the maximum (saturation) mixing ratio allowed by the U. S. Standard Atmosphere, 1962.

A recent report by Scholz et al (1970) gives the results of an analysis of a sample of stratospheric air which was collected over an altitude interval between 44 and 62 km over White Sands, New Mexico on 4 September 1968.

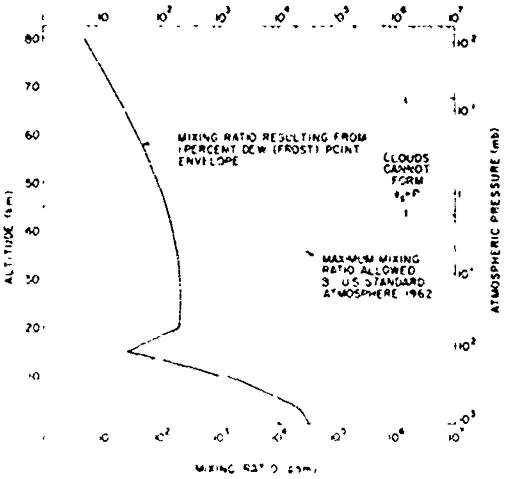

Figure 6. Mixing Ratio Envelope Resulting from the Upper 1-percent Dew-(frost)-point Temperature Envelope Presented in Figure 5. Maximum (saturation) mixing ratio allowed by the U.S. Standard Atmosphere, 1962, is shown for comparison (e_s is saturation vapor pressure; P is atmospheric pressure)

The stratopause water vapor concentration was determined to be between 3 and 10 ppm (by volume). These values were considerably lower than the mixing ratio envelope shown in Figure 6 for that altitude range; but there is no reason to expect a single measurement over White Sands would equal a 1-percent wettest month and wettest geographical area extreme.

The 5-percent upper humidity extremes have not been included in either Figures 5 or 6 due to the small differences (about 2.5°C) from the 1-percent values. The dew-point temperatures for the 5-percent envelope are presented in Table 3.

4. SUMMARY

The 1-percent and 5-percent high humidity extremes for selected levels, recommended for use in MIL-STD-210B are presented in Table 3 (graphically in Figures 5 and 6). For altitudes from the surface to 10 km, for which there are sufficient data to statistically establish the upper 1-percent and 5-percent extremes, the dew-point envelope is considered accurate to about ±1°C. For altitudes between 10 and 80 km, where the envelope can be considered only as a model, the frost-point estimates could well differ from true values for risks specified by a few degrees. However, for internal consistency, dew- (frost)-point values in Table 3 are given to the nearest 0.5°C and mixing ratio to the nearest ppm.

It should be emphasized that these envelopes cannot be interpreted as profiles, since values for the various altitudes may not correspond to one another in either time or space, and that the air temperature data in Figures 5 and 6, presented only for comparison, were derived independently of humidity. It would not be unreasonable, however, to accept short portions of the envelope, say 2-km intervals, as typical upper 1-percent or 5-percent dew- (frost)-point profiles avoiding, of course, the break points at 15 and 20 km.

Table 3. 1- and 5-percent High Dew- (frost)-point Temperature (°C) and Corresponding Mixing Ratio (ppm) for Selected Levels

Altitude (km)	Upper 1 percent		Upper 5 percent	
	Dew (Frost) Point (°C)	Mixing Ratio (ppm)	Dew Point (°C)	Mixing Ratio (ppm)
0	33.5	33,466	32.0	30,626
1	29.0	29,014	27.5	26,487
2	25.0	25,806	22.5	22,073
3	20.5	22,148	16.5	17,102
4	13.0	15,480	10.0	12,634
5	6.0	10,951	3.0	8,846
6	-1.0	7,576	-4.0	6,050
7	-8.5	4,917	-10.0	4,367
8	-15.0	3,358	-16.0	3,090
9	-22.0	2,140	-23.5	1,873
10	-29.5	1,257	-32.0	990
12	-45.0	231		
15	-66.0	24		
20	-56.5	195		
25	-62.0	203		
30	-67.5	200		
40	-78.5	156		
50	-89.5	85		
60	-100.5	38		
70	-111.5	14		
80	-122.5	5		

5. ADDENDUM

During final review of this manuscript (prior to printing), the authors received a newly published upper-air atlas for the Southern Hemisphere which presents, among other variables, mean monthly dew-point temperatures for the surface and selected pressure levels to 500 mb (Taljaad et al, 1969). A survey of this atlas supports the previous findings that the worldwide, high-extreme dew points are found in the Northern Hemisphere. The highest Southern Hemisphere mean dew-point temperatures at the surface and the 850-mb levels (for the most extreme month, January, and extreme location, the Amazon River regions) are only 1 to 2°C lower than the comparable 50-percentile values at those locations which were used in establishing the 1-percent envelope developed herein.

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13. ABSTRACT

The 1- and 5-percent world-wide high dew-point envelopes from the surface to 10 km are derived statistically from operational rawinsonde data. Values at each level are based on the most extreme month at the most extreme location, as required for the revision of MIL-STD-210A, "Climatic Extremes for Military Equipment." A 1-percent frost-point envelope model is extended to 80 km. It is based on limited experimental data and theory. Dew- (frost)-point envelopes and corresponding mixing ratios are tabulated to 80 km.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
High humidity extremes Stratospheric humidity Dew-point envelopes						

Unclassified

Security Classification